
GENERAL ASPECTS OF NONDESTRUCTIVE INSPECTION

The Reliability of Soldered Joints Produced at a Low Temperature

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Received February 15, 2013

Abstract—Under severe service conditions of electronic instruments (at elevated temperatures and vibrations in electronic systems), failures in their operation frequently occur. Severe intrinsic thermal conditions of operating instruments may cause such failures. However, malfunctions in electronic devices may often be due to defects in soldered joints that were made at lowered temperatures. An approach is proposed that makes it possible to considerably improve the reliability of soldered joints.

Keywords: defect, quality, testing, soldering iron, temperature, thermal conductivity coefficient

DOI: 10.1134/S1061830913090088

INTRODUCTION

Failures most frequently occur in instruments that operate under conditions of elevated temperatures, vibrations, etc., for example, in instruments for controlling leaks from gas and oil pipelines using optical–electronic systems (OESs) [1], gauges for monitoring the thickness of produced rolled sheets [2], etc. Some developers are inclined to consider that frequent failures occur due to severe thermal and vibration conditions that are caused by various factors, including internal thermal and vibration operating conditions of instruments [2, 3]. However, even if severe thermal and vibration conditions, under which instruments operate, are eliminated, the causes of frequent system failures do not always disappear.

Experimental data show that failures in testing systems that are under the conditions of elevated temperatures and vibrations, can be also frequently determined by defects in soldered joints. Frequent failures of automation systems lead to a significant decrease in the working efficiency. Therefore, along with the further development of the trends that provide direct testing of the initial materials, parts, and articles [4–6], methods for increasing the failure-free operation of instruments via the provision of optimal conditions of technological processes and use of appropriate operating tools are becoming more and more urgent [7, 8].

When space-wired interconnections are performed, pilot instruments are manufactured, and electronic devices are tuned and repaired, foreign and domestic manual soldering stations are widely used as soldering instruments. In this case, “...electric soldering irons remain mass products of ERSA and can be found in any shop in Germany relating to electricity and repair. They cover a power range of 5–550 W and have different designs...;” soldering and repair stations are the most needed tools for professional and amateur applications in electronics” [8]. Up to now, soldering tools are used in the cases where the reliability of soldered joints is of fundamental importance.

The soldering temperature exerts a determining effect on the quality of soldered joints. On the other hand, the analysis of various sources on contact soldering of electronic devices shows that the engineering literature does not contain scientifically substantiated information on the influence of the parameters of a soldering iron on the temperature gradient along its length.

The temperature sensor of the soldering station is located in the zone of the heating element. The temperature of the soldering end of the soldering iron is always lower than the temperature of the case of the soldering tool. According to our data, this difference may reach several tens of degrees. Therefore, the soldering temperature that depends on the parameters of the soldering iron and its temperature before soldering is not controllable [7, 8].

In particular, soldering with the ПЮС61 solder alloy at a lowered temperature leads to the formation of so-called “cold” soldering and insufficiently strong soldered joints.

The optimal interval of soldering temperatures is comparable with the value of the temperature difference along the soldering iron length. Hence, the fraction of defective soldered joints that are due to the disregarding of this difference may be as high as 100%.

Thus, the urgency of studying the influence of the parameters of the soldering iron on the temperature difference along its length is obvious.

INFLUENCE OF THE PARAMETERS OF A SOLDERING TOOL ON THE VALUE OF THE CORRECTION TO TEMPERATURE READINGS OF THE SOLDERING STATION

In order to deduce formulas, let us accept a number of assumptions:

- (i) The temperature gradient in the radial direction of the soldering iron is absent;
- (ii) The coefficients of the thermal conductivity of the soldering iron material and heat exchange between the soldering iron and air are constant in the considered temperature range;
- (iii) The soldering-iron profile is constant along its length;
- (iv) The temperature is measured relative to the temperature of ambient air.

The equation for the heat balance for any soldering iron cross section then has the following form [9]:

$$-\lambda S_1 \frac{dt}{dx} \Big|_x + \lambda S_1 \frac{dt}{dx} \Big|_{x+dx} = tP\alpha dx \quad (1)$$

or, after transformations,

$$\frac{d^2 t}{dx^2} - \frac{tP}{\lambda S_1} \alpha = 0, \quad (2)$$

where x is the distance from the case of the soldering tool along the length of the soldering iron, m; S_1 is the cross-sectional area of the soldering tool, m²; P is the perimeter of the soldering tool cross section, m; t is the temperature, °C; λ is the thermal-conductivity coefficient, W m⁻¹ °C⁻¹; and α is the heat-emission coefficient, W °C⁻¹ m⁻².

Using the equation for a heat-balance at the end of the soldering iron, we can write

$$-\lambda S_1 \frac{dt}{dx} \Big|_{x=L} = \alpha S_1 t \Big|_{x=L}, \quad (3)$$

where L is the length of the soldering tool, m.

Taking the expression for the temperature t_1 at the end of the soldering iron and recommendations from [9] into account, the final expression has the form

$$t_c \approx t_1 \frac{e^{mL} + e^{-mL}}{2} \equiv t_1 \cosh(mL), \quad (4)$$

where $m = \sqrt{\frac{\alpha P}{\lambda S_1}}$.

The power released by the soldering iron into air is equal to the amount of heat that is supplied to the soldering iron base; then,

$$P_{st} = \lambda S_1 m t_c \tanh(mL), \quad (5)$$

where t_c is the temperature of the case of the soldering tool (temperature sensor), °C.

According to our experimental data, $\tanh(mL) < 0.5$. Subsequently, using the expansion of hyperbolic cosine into a series for a soldering iron with a circular cross section, we obtain [9]

$$\Delta t_{c1} = t_c - t_1 \approx t_1 L^2 \frac{2\alpha}{\lambda d}. \quad (6)$$

Thus, as follows from formula (6), the temperature difference between readings on the display of the soldering station and the actual temperature at the soldering end is proportional to the square of the soldering iron length and inversely proportional to the soldering iron diameter.

THE THERMAL EFFICIENCY OF A SOLDERING TOOL

Among the characteristics of a soldering tool, such an indicator as its thermal efficiency EF [10] is mentioned by researchers in the field of contact soldering.

In monograph [10], the author gives the following definition for the EF_m of a soldering tool: this is “the ratio of the amount of heat supplied to the soldering iron to the heat released by the heating element.”

If the soldering tool has a circular profile that is constant along its length, the power dissipated from the soldering iron can be determined as [9]

$$\tanh(mL) \approx mL. \quad (7)$$

Taking expression (6) into account, the efficiency EF_m of the soldering tool as the ratio of the amount of heat supplied to the soldering iron to the heat released by the heating element can be calculated from the formula

$$EF_m = \frac{\pi \alpha d L t_c}{4 P_{xx}}, \quad (8)$$

where d is the diameter of the soldering iron, m ; P_{xx} is the power of the soldering iron without a thermoregulator, which is given in its certificate and required for heating the soldering iron to the idle-running temperature, when no soldering is performed and the temperature remains constant. If necessary, it can be refined by measuring the supply voltage and consumed current in the steady-state idle-running mode.

For example, for a 15-W soldering iron at $t_c = 300^\circ\text{C}$ with a 3-mm-diameter and 5-cm-long (from the case) soldering iron, the efficiency EF_m is about 12%.

It should be born in mind that the above example characterizes the most typical soldered joints and soldering regimes. In practice, one also has to deal with unique soldered joints. These are most frequently space-wired interconnections, wide printed conductors or a printed-circuit board screen, mounting of microunits on a dielectric with a high thermal conductivity, and soldering of pins and tabs that are installed on massive bases.

In all these cases, the heat absorption during soldering may be much higher than when ordinary joints are soldered.

According to this definition, the efficiency EF_m of a soldering tool with an internal heater is always equal to unity because the soldering iron and the case form a single unit. Thus, such a soldering tool has a 100% efficiency, although the entire energy is uselessly expended for air heating.

This means that the definition of the efficiency, EF_m , by G. Manko is not quite correct because the useful work for a soldering tool is the heating of soldered joints. Therefore, along with relationship (8), we proposed another definition for the efficiency of a soldering tool. The efficiency EF_t is the ratio of the heat absorption (the amount of heat transferred to soldered joints) to the power of the soldering tool during soldering:

$$EF_t = P_1 / (P_{xx} + P_1). \quad (9)$$

CONCLUSIONS

As a result of the performed analysis, the following conclusions can be drawn.

(1) A formula that allows estimation of the temperature difference along the length of the soldering iron is proposed. A discrepancy between the readings of the temperature sensor of the soldering station and the temperature of the soldering iron end increases, as the length of the soldering iron increases and its diameter decreases.

(2) Under the conditions of batch production, it is necessary to periodically monitor the temperature of the soldering iron end of a soldering station using supplementary instruments. Additional monitoring of the temperature of the soldering iron end must be performed more frequently for soldering irons with shorter lives. If it is difficult to measure the temperature of the soldering iron end, it can be recommended to periodically control the length of the soldering iron with the subsequent correction of the displayed temperature on the indication panel of the soldering station.

(3) An expression for the thermal efficiency of a soldering tool was obtained (according to the definitions of G. Manko and the authors of this paper).

The use of the results of the analysis makes it possible to significantly reduce the probability of instrument failures and reduce the frequency of failures in electronics, even in the cases where automation

devices are under severe thermal and vibration operating conditions, which are determined by both internal and external factors [2, 3, 11].

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Translated by A. Seferov